

DRAFT SF 298

1. Report Date (dd-mm-yy)		2. Report Type		3. Dates covered (from... to)	
4. Title & subtitle Rapid Inspection of Tubing and Piping Due to Corrosion-Related Problems Tri-Service Conference on Corrosion Proceedings				5a. Contract or Grant #	
				5b. Program Element #	
6. Author(s) Susan W. Borenstein Robert McCullough James Doyle				5c. Project #	
				5d. Task #	
				5e. Work Unit #	
7. Performing Organization Name & Address				8. Performing Organization Report #	
9. Sponsoring/Monitoring Agency Name & Address Tri-Service Committee on Corrosion USAF WRIGHT-PATTERSON Air Force Base, Ohio 45433				10. Monitor Acronym	
				11. Monitor Report #	
12. Distribution/Availability Statement Approved for Public Release Distribution Unlimited					
13. Supplementary Notes					
14. Abstract					
15. Subject Terms Tri-Service Conference on Corrosion					
Security Classification of			19. Limitation of Abstract	20. # of Pages	21. Responsible Person (Name and Telephone #)
16. Report	17. Abstract	18. This Page			

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TRI-SERVICE CONFERENCE ON CORROSION



21-23 JUNE 1994

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**Rapid Inspection of
Tubing and Piping Due to
Corrosion-Related Problems**

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ABSTRACT

Military and commercial power-generating facilities often have failures to tubing and piping systems. In addition, marine tubing and piping systems are subject to increasing demands for better performance and longer service life. Primarily, the systems are degraded by fouling and corrosion. These can affect flow, heat transfer rates or structural integrity. This paper will discuss the failure modes, such as fouling and corrosion, particularly microbiologically influenced corrosion (MIC). MIC is the term for deterioration of metal by corrosion processes that occur either directly or indirectly as a result of the activity of organisms or their metabolites. Inspection methods for these degradation mechanisms are discussed. In addition, an advanced inspection system which integrates laser profilometry and fluorescence spectroscopy in a single probe is discussed. The probe scans the internal length of tube or pipe and generates a topographic map of the surface and characterizes the corrosion deposits to assess the severity of wall loss or pitting and the presence of deposits.

INTRODUCTION

Microorganisms have the capability to adhere to surfaces, grow and produce biofilms. Often biofilms create difficulties when they form, such as when slimes are produced on heat exchanger tubes and heat transfer capabilities are reduced. Sometimes corrosion occurs beneath the biofilm. Microbiologically influenced corrosion (MIC) is the term for the initiation or acceleration of corrosion by microorganisms or their metabolites, usually on metal surfaces.¹

Biofilms are usually made up of extracellular polymers (exopolymers) and a consortium of sessile organisms, debris and organic matter.^{1,2} The extracellular polymers are secretions that form a matrix of fibers and often envelop the organisms and contribute to collecting other material. Biofouling is the biological growth on surfaces in contact with natural water.² Biofouling often leads to corrosion underneath the deposits formed on metal surfaces.

The study of MIC and the need for better monitoring and inspection methods are relatively recent events. MIC monitoring and inspection is more complex than "normal" corrosion.^{3,5} First, more than one corrosion mechanism may be involved. Second, MIC is associated with extremely diverse microbiological environments. Inspection methods need to be able to detect diverse corrosion mechanisms on a wide variety of materials and components.^{6,7}

BACKGROUND

Several types of corrosion mechanisms are associated with military and commercial power-generating facilities. These include general corrosion, pitting, underdeposit or crevice corrosion, and MIC. Less commonly occurring problems include corrosion-assisted cracking and velocity-assisted corrosion.

Classifying corrosion can often be difficult. General corrosion is a general uniform loss of metal: usually a small amount over a large area. This is the form of corrosion (in almost every case) for which corrosion rates are tabulated. In contrast, localized corrosion is selective attack, such as pitting. For example, a large portion of the surface area of a pipe may be unaffected, and rapid corrosion occur at the weldments. Failures of this type may result in costly problems and may be difficult to monitor and

inspect. Lack of understanding the distinction between corrosion rate measurements, resulting from general corrosion, and localized corrosion may also lead to expensive problems and possible failures.

Crevice corrosion is another localized form of pitting corrosion. Crevice corrosion typically occurs under deposits or in crevices between mating surfaces, such as gasketed flanged connections. Often it occurs on film-protected (passive) metal surfaces, such as austenitic stainless steels. Some instances of MIC may be considered a form of crevice corrosion when the exopolymer film formed by the microorganisms creates a "living crevice", as shown in Figure 1. The role of organisms relates to the influence of differential aeration cells forming under a biological deposit where a pit initiates and tubercle forms.¹

DISCUSSION

Difficulties arise with characterizing MIC and biofouling on metal surfaces. To what extent are organisms involved and is the **microbiological** species important? Is the microbial ecology important or relevant? How much are the organisms involved and how do they **influence** the surfaces? What **corrosion** mechanisms are involved and are there any differences than in underdeposit corrosion without microorganisms involved? The following discussion highlights these three aspects of MIC as they relate to monitoring and inspection of biofouled surfaces.

Monitoring and Inspection Techniques

Microbiological analysis has frequently been done in conjunction with monitoring MIC of metals, particularly in problems of corrosion associated with the oil and gas industries. Sulfate reducing bacteria (SRB) and their action upon metals was the basis of a theory by von Wolzogen Kuhr and van der Vulgt.⁸ They theorized that the corrosion of iron buried in an aerobic soil was the result of activity by SRB. Since then Little and Wagner⁹ note, in addition to the SRB, the iron-oxidizing, sulfur-oxidizing bacteria and many other organisms have been shown to influence corrosion of metals. Borenstein and Licina⁵ discuss microbiological analysis methods.

It must be clarified that the presence of microorganisms in a fluid or in a deposit does not indicate how or how much those organisms may have influenced corrosion if they influenced it at all. Surfaces exposed to environments with biological activity would **always** be expected to have organisms present on the surfaces, often in very high numbers. The

organisms **may or may not** have been involved in or even a primary factor in corrosion. Examination of surfaces for chemical species produced by the microorganisms which interact with the metal surface to produce corrosion, or mineralogical "fingerprints" can be useful in determining the microbiological influence.¹⁰ McNeil and Little have found that certain types of corrosion products can be formed only in environments by biological processes. A fingerprint indicator occurs when minerals form that are not consistent with those able to form in normal environmental conditions. The direct cause-and-effect relationship between microbiology or microorganisms adhering to surfaces and corrosion occurring underneath is often difficult to establish.

The importance of inspection and the ability to decrease operation and maintenance costs by inspection prompted changes in inspection routines in the 1980's. A variety of established techniques were used and improved upon and innovative techniques are being developed that apply to inspections for MIC and other forms of corrosion. These include:

- performance monitoring
- nondestructive testing
- advanced techniques

Performance Monitoring

The performance of a system often gives an indication that problems are developing. Changes in temperature, pressure, and flow rates may indicate early signs of fouling in a heat exchanger, for example. Unfortunately, performance monitoring is not specific. The root cause of the problem is often not apparent from indirect records, so attempts to resolve a problem are often limited. Performance monitoring is not a corrosion monitoring technique, but is sometimes perceived to be.

Nondestructive Testing

Inspections normally begin with nondestructive examination to evaluate the condition of a system or component. Some combination or coordination of techniques is also common. Common inspection methods include:

- Visual Testing (VT)
- Ultrasonics Testing (UT)
- Magnetic Particle Testing (MT)
- Liquid Penetrant Testing (PT)

- Eddy Current Testing (ET)
- Radiographic Testing (RT)

Visual examination is used extensively. Based on what can be seen with the naked eye or with low powered optical lenses it is often the least expensive inspection method. Conditions of MIC, as well as biofouling, and various corrosion problems may be documented using a 35mm camera and closeup lenses. Pipe crawlers, et al., can perform remote visual inspections of interior surfaces.

Ultrasonic inspections use high frequency sound waves to detect both surface and subsurface flaws. The sound waves travel through the material and are reflected from interfaces. Flaws are detected by analyzing the reflected beam. Ultrasonic testing is sometimes unsuitable for MIC and corrosion problems because the rough or irregular surface gives difficult to interpret signals.

Liquid penetrant inspection reveals discontinuities that are open to the surface such as pits or cracks. After liquid penetrant is applied to the surface, the penetrant dye seeps into the discontinuity. Excess penetrant is cleaned away and a development powder is applied to the surface to draw out the dye from the discontinuity. It is sometimes suitable for corrosion and biofouling related problems. Not suited to field inspection of tubes or pipes.

Magnetic particle inspection is useful for inspecting ferromagnetic materials with surface or near surface discontinuities or flaws. The principle of operation relies on the nature of the material and the fact that when a metal is magnetized, the magnetic field formed is very sensitive to flux leakage at cracks or discontinuities. Although it is usually useful for surface flaws, it is sometimes suitable for MIC, corrosion, and biofouling-related problems.

Eddy current inspection is based on the principles of electromagnetic induction and may be used for ferrous and nonferrous alloys - although eddy current examination of ferrous alloys is much more limited. For example, plants often use eddy current testing for examining tubing for internal corrosion or damage. The induction coils are inserted into the tubing and indications can be determined by the change in flux of the induced current through the coil. From these effects, an estimate of defect thickness can be made. The accuracy and reliability is sometimes poor.

Radiographic testing uses either x-ray or gamma rays. When an object is exposed to radiation, the radiation will, in various measures, be absorbed, scattered or transmitted. The transmitted image is recorded on photographic film. Differences in film density are related to the thickness, including the flaws. For example, a pit would appear as an indication on the film. Radiography can be very useful for MIC or corrosion related problems. It is particularly useful for determining the extent of pitting of weldments.

Advanced Techniques

Advanced inspection techniques vary in complexity, maturity and capability. Selection of a method for inspection of flaws depends on a number of variables including:

- Nature of the flaw
- Accessibility of the flaw (such as at a weldment)
- Type of material
- Part geometry
- Number of items to be inspected
- Capabilities of the inspection method
- Level of inspection quality desired
- Economic considerations

Laser profilometry, such as the LOTIS™ technique developed by Quest Integrated, Inc., of Kent, Washington, uses a laser source, optic, and a photodetector in the front section of the probe for internal inspection of tubing.¹¹ Doyle discusses how this is useful for inspection systems that can rapidly scan the full length of a marine boiler tube, generate a quantitative topographic map of the tube surface, and tabulate a summary of the results (Figure 2). Internal corrosion and pitting are the primary mechanisms of degradation the system was designed to examine. It provides a high degree of precision and accuracy and distinguishes between cracks, pits and other defects. LOTIS is now being used to inspect heat exchanger and condenser tubes in both military and civilian applications.

An advanced inspection system is currently under development to identify and characterize MIC-affected tubing and piping through the use of advanced, cost-effective NDE methods. The system employs a noncontacting, laser-based sensor assembly that is capable of "fusing" laser-based profilometry and fluorescence spectroscopy data obtained using a single probe. The resulting inspection system will be capable of

rapidly and accurately scanning the length of a tube or pipe and generating a detailed topographic map of the internal surface. Superimposed on this image will be a false-color map that identifies the presence of MIC. The results will be displayed in a number of computer-graphic formats that will allow operators to quantitatively assess the level and severity of wall loss due to pitting and determine the presence and extent of MIC-affected surfaces.

FATS (Focused Array Transducer System) developed by Infometrics of Silver Spring, MD, is a UT system that improves the performance of ultrasonic examinations. Conventional UT techniques can be improved by using a focused transducer, made up of phased arrays of transducers and sophisticated electronics (Figure 3). In addition, the technique can be partnered with TestPro, also developed by Infometrics. TestPro is a data acquisition system with enhancement features.

CONCLUSIONS

Selection of inspection tools must focus on:

- resolution capabilities
- speed of inspection
- compatibility with operations and maintenance activities

New techniques, such as laser profilometry and the focused array transducer system, may provide greater resolution and specificity for unique problems.

ACKNOWLEDGEMENTS

We thank Mr. George Licina of Structural Integrity Associates, Inc., San Jose, CA and Mr. George Nekoksa of Corrosion Failure Analysis and Control, San Ramon, CA for their review of the manuscript.

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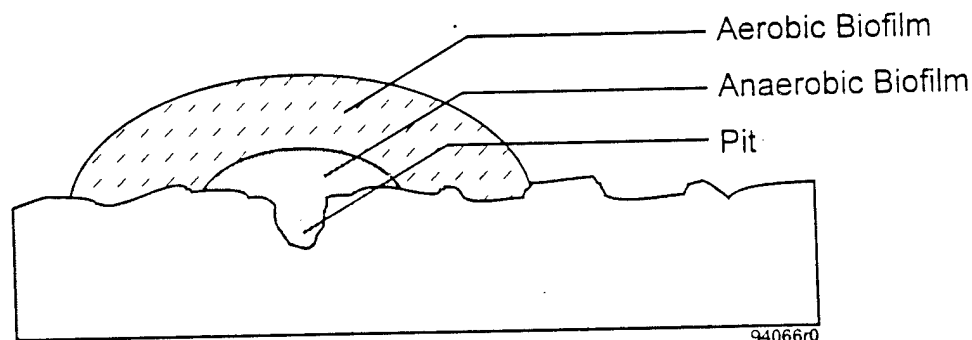


Figure 1. Biofilm Over Pitting Corrosion

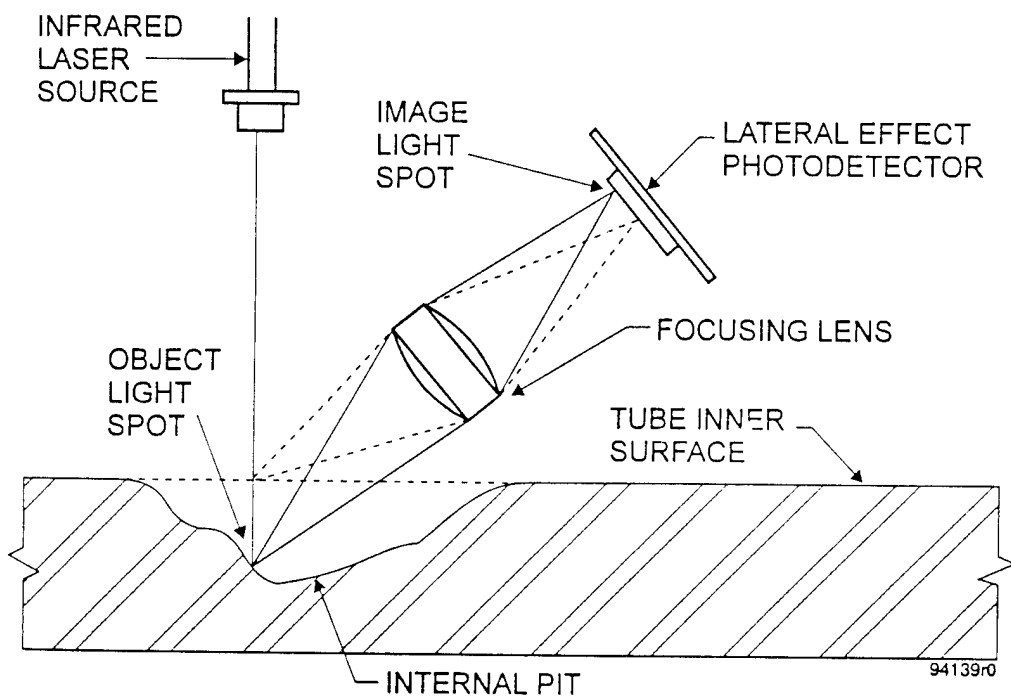


Figure 2a. Operation of Laser Scanner

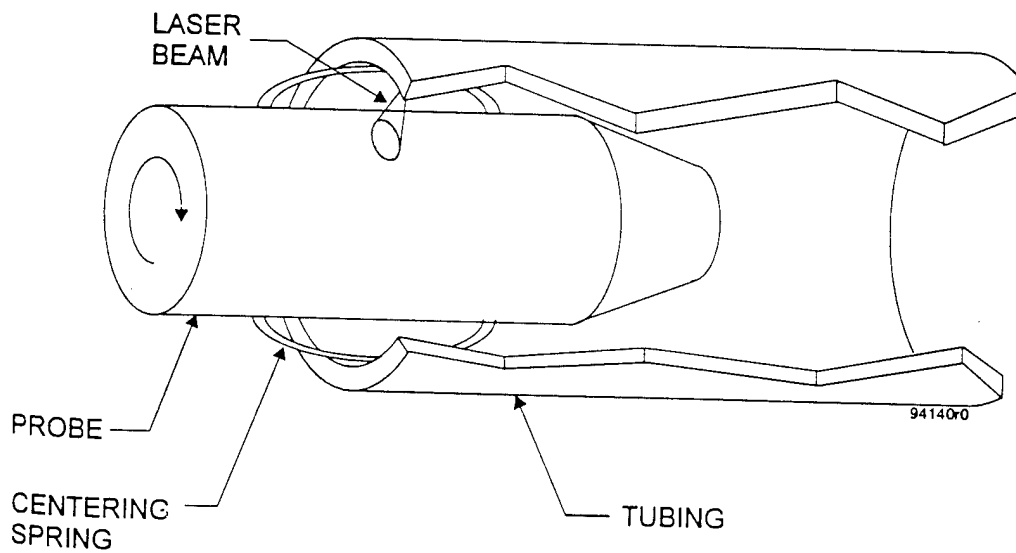


Figure 2b. Optics Housing of LOTIS™ Generates a Helical Map of Tube 1D

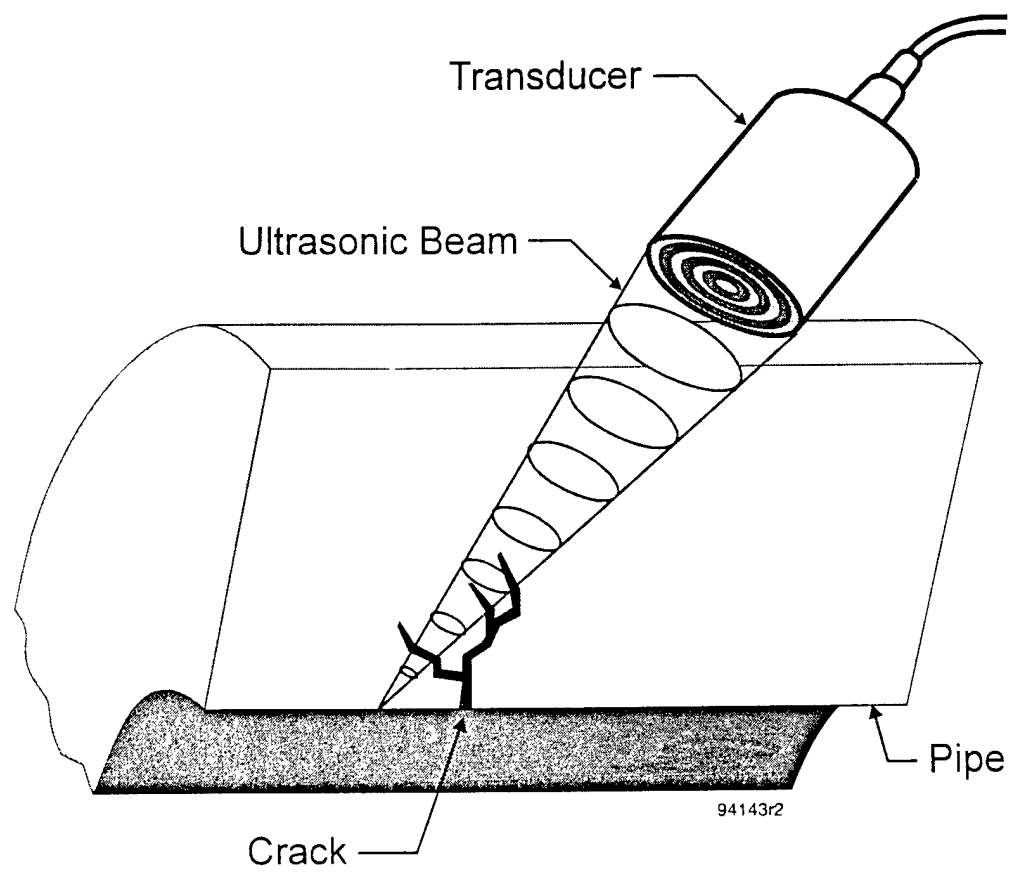


Figure 3 Focused Ultrasonic Beam Using Multiple Transducers